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Spatial and Temporal Characteristics of Paleoseismic Features in the Southern Terminus of the New Madrid Seismic Zone in Eastern Arkansas

PROGRAM ELEMENTS: I & II

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TECHNICAL ABSTRACT

The focus of this project was to identify and characterize specific features related to historic or prehistoric earthquakes near the southern terminus of the New Madrid Seismic Zone in eastern Arkansas. The investigation concentrated on accomplishing four main goals: (1) detailed aerial and land surveys to identify and locate features potentially related to historic or prehistoric earthquakes; and (2) to trench, log, and sample four sites that exhibit characteristics of seismic activity; (3) apply geophysical technique (Ground Penetrating Radar) to study the signature of the sand blows on the reflected radar waves; (4) Landsat image analysis to locate areas potentially disturbed by severe ground shaking.

Recently conducted aerial surveys, field surveys, and trenching reveal the existence of several liquefaction features (sand blows) and linear features as far as south of Marianna, Arkansas. This is more than 100 kilometers from the currently active segments of the New Madrid Seismic Zone. We believe the discovered seismogenic features are significant for the following reasons: (1) They are at considerable distance from present-day earthquake activity. The implication of this is that they represent a new earthquake source region not previously recognized, or that they were caused by an earthquake(s) of very large magnitude in the source region of the New Madrid Seismic Zone. (2) These features have very large dimensions (~110 by 60 meters), resembling features in the immediate vicinity of the New Madrid Seismic Zone. The implication of this is that no matter where the source region is, the ground shaking was significantly severe in order to generate them. (3) Potentially, detailed investigation of these features will have important implications for earthquake risk mapping in the central United States. (4) They may provide important constraints on the southern terminus of the New Madrid Seismic Zone and the magnitude of the characteristic earthquake in the region.

Four trenches at three sites were excavated during the summer and fall of 2000. Two of these sites were near Marianna, Arkansas (Nancy 1 and Nancy 2) and one near Parkin, Arkansas (Parkin 1). One trench was excavated at Nancy 1 and two trenches were excavated at Nancy 2. Each of the excavations exposed a fine to medium grained sand overlying a thick clay unit. The surficial sand was found to be fed by numerous vertical to shallow dipping sand dikes <1cm to 20cm thick. Forty-five near vertical dikes were logged at Nancy 1 whereas only 3-5 dikes were exposed in the trenches at Nancy 2. Parkin 1 was also trenched to investigate a 1.5 km long linear feature. The lineament trends N56°E and has a ground-surface elevation that is 2.75 meters higher to the southeast. No fault was discovered in the trench; however, sand and clay layers tilted to the northwest were exposed suggesting possible subsurface faulting. Geophysical work (GPR) was conducted in three sites near Mariana. Results indicate the high potential of GPR for being a very promising, cost-effective tool for the study of sand blows. The size of the liquefaction features and the distance of 100 km from the active NMSZ require either a major New Madrid earthquake or a more local seismogenic source.

NON-TECHNICAL ABSTRACT

The characteristic earthquake in a region is an earthquake that occurs at approximately equal time intervals and has approximately the same magnitude and other characteristics. Knowledge of the characteristic earthquake is extremely important in assessing seismic risk in a region. Paleoseismology, the study of the occurrence, size, timing, and frequency of prehistoric earthquakes, has been found to be the most reliable method for determining the characteristic earthquake in the central United States. Knowledge of prehistoric earthquakes, particularly the return periods of large earthquakes, is important because the return periods are often much longer than the limited historic record of seismic activity. The most useful paleoseismic technique in the central United States is the identification and study of liquefaction features. Liquefaction is a common phenomenon in unconsolidated near-surface sediments in moderate to large earthquakes in which water-saturated sediment, when shaken, behaves as a liquid rather than a solid. This liquefied sand is often extruded onto the surface as a sand blow. Ancient seismic events can therefore be recognized by the presence of sand blows, which themselves may be radiocarbon dated to determine the age of the earthquake.

The nature and extent of paleoseismic features in northeastern Arkansas and adjacent areas of the New Madrid Seismic Zone is well known. The extent of these features south of the NMSZ, however, is not well investigated. Recent aerial and fieldwork by the PI's has identified paleoseismic features approximately 100 km south of the southern terminus of the NMSZ, the most distant features identified to date. This study was proposed to characterize the features by geological and geophysical methods such that the nature and age of the features can be determined. Results from this study are expected to have important implications for the magnitude of the characteristic earthquake and seismic hazard assessment and mapping in eastern Arkansas.

Introduction

A basic assertion of paleoseismological studies is that large magnitude earthquakes, ≥ 6.4, may leave a historical record in the form of liquefaction-related features. Primary among these features are sand blows, in which sand and water are extruded to the surface during episodes of strong shaking. The presence of sand blows in the geologic record provides opportunity for defining the age of prehistoric events. Employing contemporary dating techniques allows for evaluation of the recurrence intervals of large, infrequent earthquakes and helps to define the long-term behavior of seismogenic fault zones (Pavlides *et al*., 1999). The past 25 years of research and data collecting concerning the seismicity of the central United States has resulted in a dramatic increase in our knowledge of this area. Our understanding of earthquake hazards in the New Madrid Seismic Zone, the Wabash Valley Seismic Zone, and other tectonically active areas throughout the central United States has been profoundly changed by the results of paleoseismic investigations. Hundreds of liquefaction features and relatively recent faults (Figure 1), believed to be the result of local earthquake ground motion, were systematically surveyed and examined by several investigators (e.g*.,* Schweig *et al*., 1992; Johnston and Schweig, 1996; Tuttle *et al.,* 1998; Li *et al.,* 1998; Guiccione *et al.,* 2000; VanArsdale, personal communication). Most efforts have concentrated on locating and chronologically tabulating these features within the current area of enhanced seismicity and the immediately adjacent regions. Limited research has been conducted to locate and study such features outside the currently known source region.

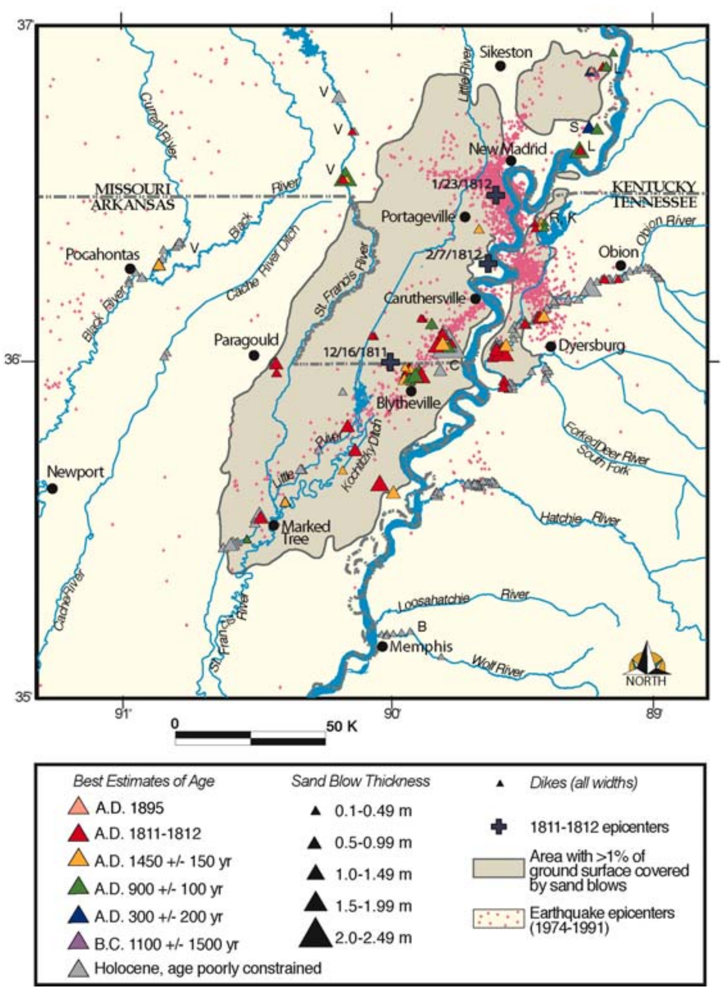


Figure 1. Paleoseismology in the New Madrid Seismic Zone (after Tuttle et al., 2002).

From the paleoseismic research conducted in the central United States, it is clear that this area has experienced repeated earthquakes in the last few thousand years. There is also mounting evidence supporting a larger than 7 moment magnitude for some of these earthquakes. Due to the short duration of historic archiving of natural events in the central United States, paleoseismology is the primary source of information for the earthquake risk mapping process. Given the lack of knowledge about the spatial characteristics of prehistoric earthquakes in areas beyond the current microseismicity zones, and given the uncertainty in recurrence period and magnitude, earthquake hazard mapping will continue be a debatable issue and a fair subject of criticism.

In spite of the obvious need for more knowledge about the northern Mississippi embayment south and southwest of Marked Tree, Arkansas, the area remains one of the most poorly studied segments of the mid-continent seismic zone. Its prehistoric earthquake features have been (and still are) under scientific and technical analysis for more than ten years. The study area, however, has remained "on the fringe" of the work conducted north and northeast of it. The loose alluvial sediment in this area is thicker than in the area to the north, complicating the hazard-assessment process. Another complication is the continuous change of the landscape due to river meandering, flooding, and more recently, heavy agricultural activity.

Recently published information (Tuttle *et al.,* 1998) indicated that the southernmost paleoseismic features identified are located just southwest of Marked Tree, Arkansas. More recently, however, Tuttle (personal communication) has identified features as far south as Parkin, Arkansas (approximately 30 km southwest of Marked Tree). VanArsdale (personal communication) found evidence of widespread liquefaction features in the Memphis area east of the Mississippi River. The investigators of this project conducted a reconnaissance aerial and several land surveys, trenching, and Landsat ananlysis in eastern Arkansas. The surveys covered an area immediately west of West Helena to Marked Tree in eastern Arkansas. These surveys indicate (see the section on the preliminary field work) that the spatial distribution of sand blows extends to West Helena (and possibly further to the south). These newly discovered features are more than 100 km southwest of the southern terminus of the current area of microseismicity at Marked Tree. We believe that the newly discovered sand blows will have a significant impact on earthquake risk assessment in this region.

During the NEHREP 2000 funding cycle, several features located west and south of Marianna, Arkansas, were found to be sand blows (see "Trenching Results" section). Two possible hypotheses might explain their existence: (1) These features may represent a new earthquake source region in the area. If so, then this source region currently shows little activity and the potential of reactivation is unknown. Gravity and magnetic analysis in this area (Hildenbrand, personal communication) indicate the existence of a major fault, the "Arkansas transform fault", bordering the study area to the south (Figure 2). (2) The features might be related to the currently active source region of the New Madrid Seismic Zone. This places the southernmost features that we have identified approximately 100 kilometers from the source region. If this is the case, then sand blows of this size (see the section on the preliminary field work) and at this distance from the source region require a "major" earthquake.

Given these observations, the questions that need to be addressed are: (1) Where is the southern terminus of the New Madrid Seismic Zone? (2) What is the implication of the lack of knowledge concerning the regional coverage of prehistoric earthquakes on the hazard assessment process? (3) If earthquake-related features do exist in the area of study (as our recently collected data indicate), what is the relationship between these features, the 1811-1812 series, and the current microseismicity? (4) If the issue of the relationship between these features and the current New Madrid earthquake activity can be resolved, how will these new findings revise our knowledge about the magnitude of the

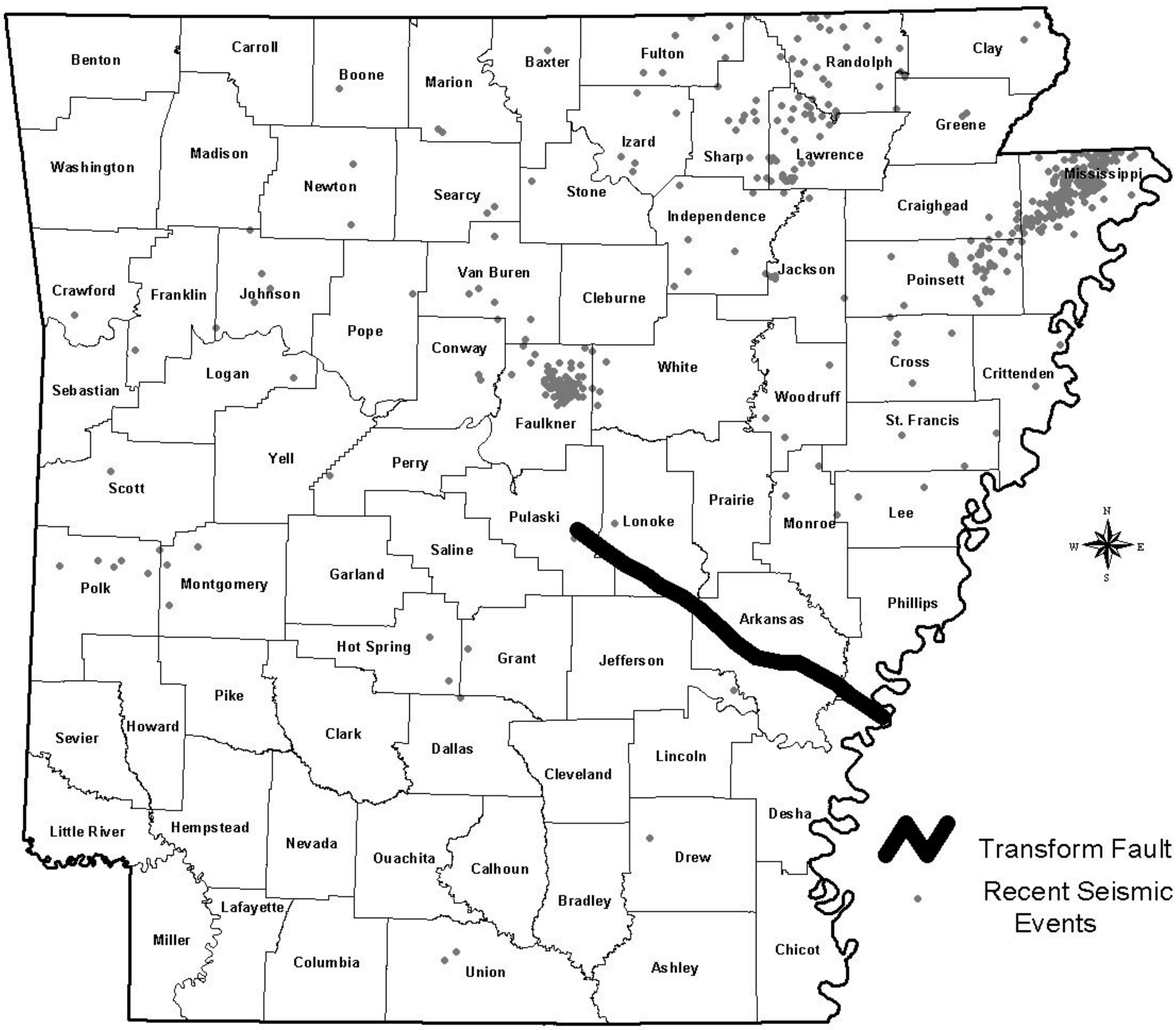


Figure 2. The Arkansas Transform fault.

characteristic earthquake, the recurrence rate, and possible migration of seismicity throughout the failed rift arm(s)? We feel that it is important to address these gaps in our knowledge about this enigmatic region through comprehensive geological, geophysical, geochronological, and archeological work in east-central and southeastern Arkansas (Figure 3).

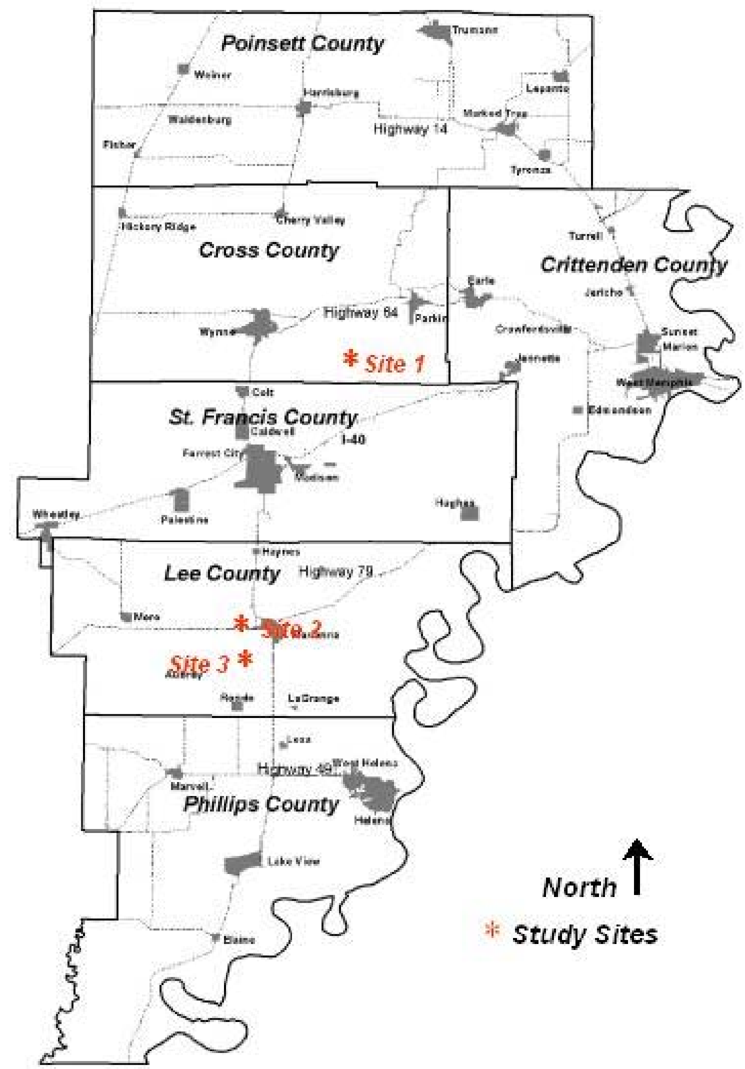


Figure 3. Location os study sites

A major scientific goal of this project is the identification and characterization of paleoseismic features in eastern Arkansas, and the relationship of these features to the currently active segment of the New Madrid Seismic Zone (NMSZ). We believe that this region may have profound implications for the ongoing seismic hazard mapping in the central United States in general, and the Memphis metropolitan area in particular. We also believe that conducting successful research in this area will help to better constrain the southern terminus of the New Madrid Seismic Zone and the seismogenic potential of other possible source regions.

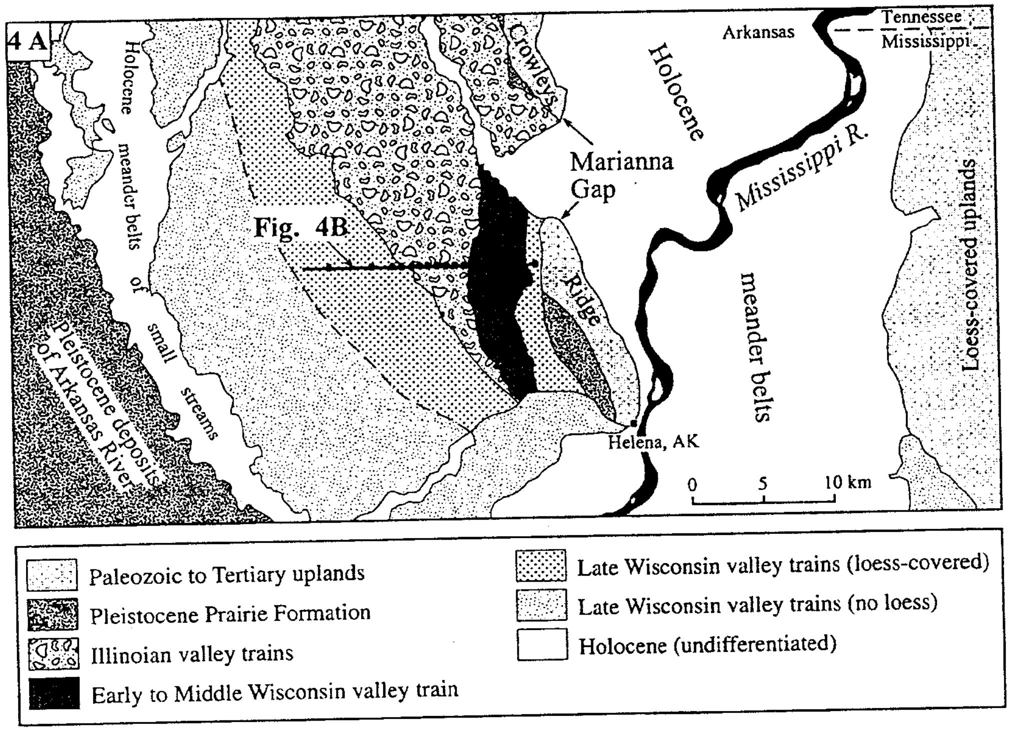
Geological and Tectonic Setting of the Study Area

The study area is located on the western flank of the Mississippi Embayment, immediately beyond the southern terminus of the NMSZ. The Mississippi Embayment is a broad south-southwest plunging trough extending from westernmost Kentucky to the Gulf of Mexico. This trough is filled with Cretaceous to recent sediments (sand, silt, clay, and gravel) of shallow marine and fluvial origin. These embayment sediments unconformably overlie Cambrian clastic and Ordovician carbonate rocks deposited in the Reelfoot rift basin. As the most prominent buried structure (graben) in the upper Mississippi Embayment, the Reelfoot rift owes its origin to crustal rifting and failure in the late Proterozoic to Early Cambrian. The aulacogen was probably subjected to a second episode of rifting and subsequent failure during the late Mesozoic (Burke and Dewey, 1973; Ervin and McGinnis, 1975). The Reelfoot rift, the focus of most of the earthquakes in the NMSZ, is about 70 kilometers wide with two to three kilometers of subsurface relief. It trends northeast to southwest for about 320 kilometers from the Rough Creek graben in Kentucky south to the Arkansas transform fault (Hildebrand and Hendricks, 1995; Langenheim and Hildenbrand, 1997). Several buried plutons border the rift to the northwest and southeast (e.g., Jonesboro pluton, Paragould pluton, and Covington pluton). The Blytheville arch, a zone of arched and faulted strata, is located in the center of the rift system (Hamilton and McKeown, 1988). The arch is approximately 15 kilometers wide, 110 kilometers long and has been mapped to within 20 kilometers of the study area.

The NMSZ has been the source of many seismic events in at least the past several thousand years. Some were large enough and had sufficient ground motion to cause liquefaction. Liquefaction from past events has been documented throughout the NMSZ (see Russ, 1982; Obermeier, 1989; Saucier, 1991; Kelson *et al*., 1996; Tuttle and Schweig, 1995 and 1996; Li *et al.*, 1998) with the southernmost features located within 19 kilometers of the northern boundary of the study area (Tuttle *et al*., 1998). Additional features have been reported near Parkin, Arkansas, only eleven kilometers to the northeast of the study area (Tuttle personal communication, 1999). Many of these liquefaction features have been associated with the New Madrid seismic events of 1811-1812. In the last few years, however, numerous other features have been correlated with older events. Kelson *et al*. (1992 and 1996), Tuttle and Schweig (1995), Li *et al*. (1998), and Tuttle *et al*. (1998) have documented liquefaction features from at least two seismic events occurring prior to the 1811-1812 earthquakes. These two events occurred A.D. 900±100 and A.D. 1530±130 and were similar in strength to those of 1811 and 1812 (Li *et al*., 1998; Tuttle *et al*., 1998).

The boundary of the study area extends from approximately 45 kilometers southwest of Marked Tree, Arkansas to south of Helena, Arkansas. The area is underlain by Cretaceous to Tertiary age sediments which range in thickness from 775 meters in the north to 930 meters in the south (Cushing *et al*., 1964; Boswell *et al*., 1965; Hosman *et al*., 1968). Mantling these sediments are fluvial and eolian deposits including multiple Pleistocene braided stream surfaces of the Mississippi River that are crosscut and/or reoccupied by Holocene meander belts of smaller streams (Boswell *et al*., 1968; Blum *et al*., 2000).

Blum *et al.* (2000) recently completed a detailed stratigraphic study of the immediate study area that included 18 cores collected along an east-west transect south of Marianna, Arkansas (Figure 4a). The transect extends approximately 25 km westward from Crowleys Ridge across four geomorphic surfaces of Illinoian through Late Wisconsin valley trains. The uppermost stratigraphic unit, the Peoria Loess, reaches 14 m in thickness and thins westward until it becomes absent west of the transect (Figure 4a, 4b). Underlying the Peoria Loess is the middle Wisconsin Roxana Silt. This massive silt



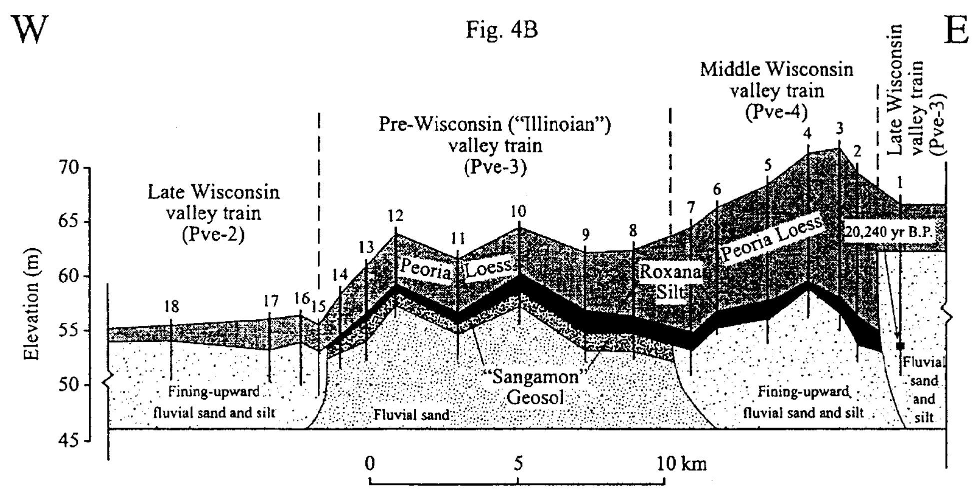


Figure 4. A) Valley Trains in the Western Lowlands of central Arkansas, B) Cross section illustrating relations between loess units and fluvial deposits in core transect shown in figure 4A (after Blum *et al.,* 2000).

unit is up to 2 m thick also thins westward (Figure 4b). These units are underlain by stratified fluvial deposits of either sand or sand and silt. Underlying the Illinoian valley train geomorphic surface, a Sangamon Geosol separates the fluvial sand from the Roxana Silt (Figure 4b). Significantly, all sand blows identified to date in this area (with the exception of one immediately south of Marianna) are within the Illinoian valley train. This valley train is unique in this area in that it is underlain by fluvial sand (rather than fluvial sand and silt) that is overlain by a clay-rich (35% clay) paleosol. This localization of sand blows within the Illinoian sequence suggests that stratigraphy is important in controlling the occurrence of liquefaction in the study area.

Analysis and Results

An aerial survey conducted by the research team in eastern Arkansas reveals numerous features throughout the research area that appear to have had a seismogenic origin (Figures 4 to 6). Most of the features south of Interstate 40 are semi-circular to elliptical in shape and are relatively large. The region north of Interstate 40 yielded fewer and more widely spaced features than the Marianna area. This region, however, has experienced more flooding than the areas to the south, and this may have obscured additional features.

Recently, the USGS (Tom Hildenbrand and Michael Rymer) provided the research team with a number of Landsat 7 images that cover central and eastern Arkansas including the study area at 30 meters resolution. Analysis of these images reveals their potential use in evaluating areas likely to contain sand blows. Figure 7 shows a Landsat image that covers an area from immediately north of Marianna, Arkansas, to south of Helena, Arkansas (see Figure 2). Note the difference in image characteristics for the two areas within the circled areas south of Marianna and northwest of West Helena. Areas within the circles exhibit a much more mottled or "patchy" appearance than those outside the circle. We interpret this to indicate that the surficial material in these areas may have been disturbed. Note that the image characteristics of these two areas differ from adjacent areas and areas of river meanders to the east of Crowley's Ridge (Figure 7). Aerial and field surveys indicate that the northern area immediately south of Marianna does contain widespread sandy patches that we identify as sand blows. The southern area has yet to be investigated in detail. Rymer (personnel communication) indicated that the area immediately south of Marianna exhibits characteristics typical of liquefied areas, and resembles earthquake liquefaction areas in California. This area coincides with the location of the Illinoian valley train area underlain by fluvial sand (Figure 3) encountered in a core transect in the region (Blum *et al.*, 2000). Our work has shown that some of these features are seismogenic in origin. This indicates that Landsat imaging, especially high resolution (15 meter), could prove to be a powerful tool for paleoseismological research in areas similar to the present study area.

Five ground reconnaissance surveys were performed in the previous year. The intent was to visit/locate features identified from the air and Landsat images and to determine which features warranted further investigation. Given time constraints and accessibility, not all of the features noted from the air and Landsat were visited during the ground reconnaissance. However, those that were visited and warranted further investigation were evaluated. Evaluations included measuring feature size and orientation, refining locations using GPS, and hand auger sampling to determine near-surface stratigraphy. Landowners of sites were identified and contacted.

None of the Marianna-area features visible from the air and Landsat were eliminated from future investigations. All sites visited were determined to be candidates for seismogenic features. For this project, we concentrated on the area south of Marianna due to its high potential of yielding information important to the seismic risk mapping in the central United States.

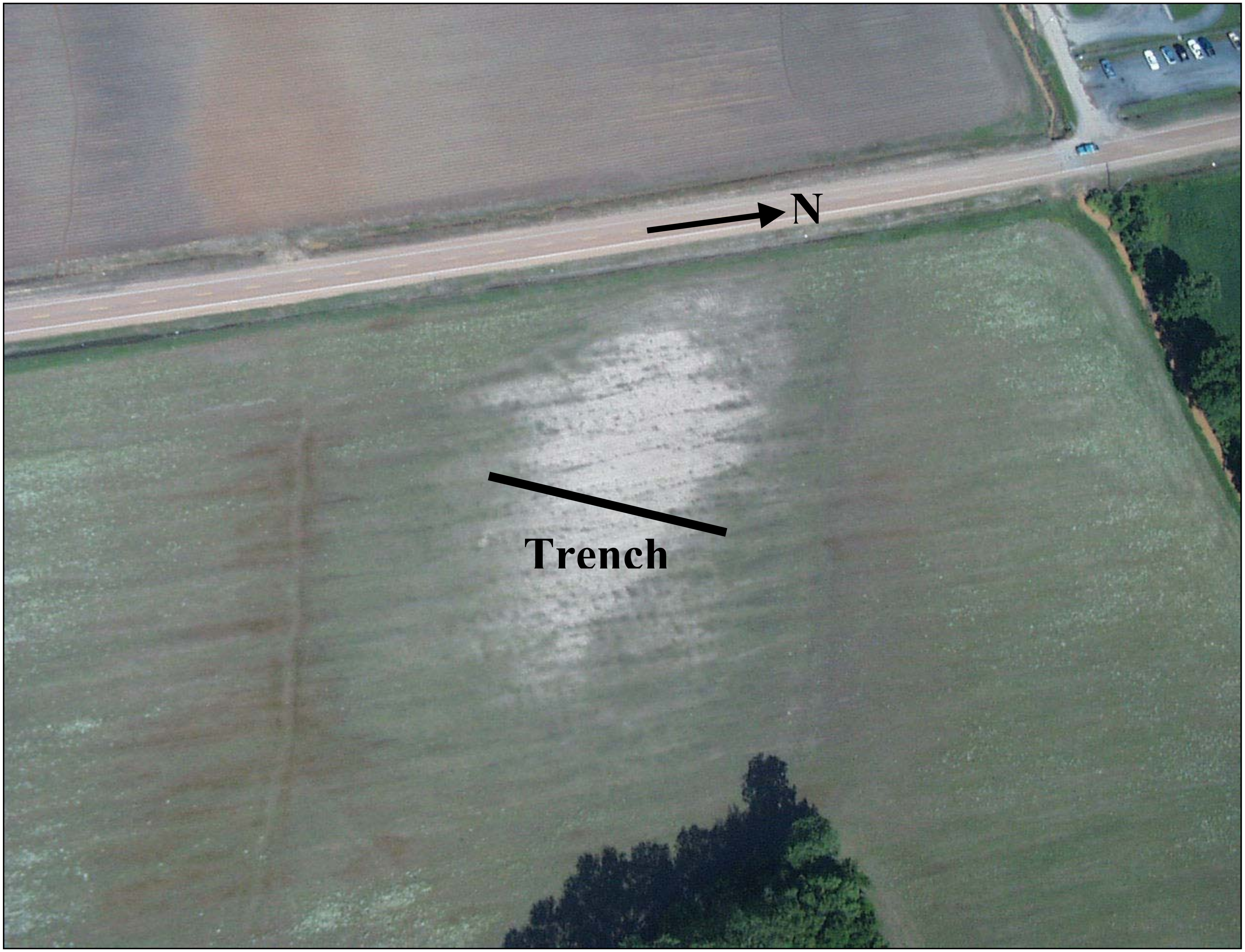


Figure 5. Aerial photograph of a sand blow (Nancy 1) just east of Marian, AR. Dark sold line indicates the location of the trench shown in Figures 8 - 10.

Figure 6. Aerial photograph of a linear feature indicated by the arrows. Dark sold line indicates the location of the trench.

Figure 7. Photograph of a sand blow (Nancy 2) just south of Marian, AR. Dark sold line indicates the location of the trench shown in Figures 11 - 14.

Figure 8. A typical trench excavated for logging and sampling. This trench is at site 2 (Nancy 1).

Trenching Results

Four trenches at three sites were excavated during the summer and fall of 2000. The dimensions of these trenches ranges between 75 to 95 meters long, 1.2 meters wide, and an average depth of 3 meters. Two of these sites were near Marianna, Arkansas (Nancy 1 and Nancy 2) and one near Parkin, Arkansas (Parkin 1) (Figure 2). One trench was excavated at Nancy 1 and two trenches were excavated at Nancy 2. Parkin 1 was also trenched to investigate a 1.5 km long linear feature. The lineament trends N56°E and has a ground surface that is 2.75 meters higher to the southeast. No fault was observed in the trench; however, sand and clay layers tilted to the northwest were exposed suggesting possible subsurface faulting. Both Nancy1 and Nancy2 sites were confirmed to be sand blows of seismogenic origin. Below is a description to the three trenches that were opened at these sand blows:

Nancy 1, T-1

A trench oriented approximately N38˚E was excavated across the short axis of an elliptically-shaped sandblow (Figure 8). The excavation was 59 meters long and ranged from 1.85 to 2.25 meters deep. The east wall was cleaned, gridded at a 50-centimeter spacing, logged in detail, and photographed. Important portions of the west wall were also cleaned and photographed. Logging revealed four distinct lithologic layers. The lowermost layer was a gray to brownish clay, which extended the entire length of the trench. The excavation exposed the upper 1.5 meters of this layer denoted as Unit B. The clay was plastic, slightly iron stained and exhibited a moderately developed soil structure (blocky) with pores and rootlets present. Some small charcoal fragments were present. No fewer than 45 vertical to near vertical sand dikes cut across Unit B feeding the ovelying sand layers. The sand dikes ranged in thickness from <1 to 20 centimeters (Figure 8). The sand layers are denoted as Units A and C and are distinguished from one another by their degree of cementation. Unit A was moderately cemented while Unit C was loose and flowed easily once dry. Both units were a fine-medium grained light gray sand with a yellowish brown iron staining mottled throughout. Charcoal fragments, roots, and animal burrows (krotovina) were present in both units although the krotovina and roots were more abundant in Unit C. A weak blocky soil structure had developed in portions of Unit A, but no such structure development was seen in Unit C. Unit A was logged throughout the trench exposure whereas Unit C was only seen in the southern 2/3 of the trench. Overlying both sand units was a plow zone of highly disturbed silty sand which ranged in thickness from 13 to 35 centimeters.

Nancy 2, T-1

A 38-meter long trench oriented N66ºE was excavated across a sandblow located at the Nancy 2 site (Figure 9). This excavation averaged 2.1 meters in depth. The northwest wall was cleaned, gridded at a 50-centimeter spacing, logged in detail, and photographed. Portions of the southeast wall were also cleaned and photographed to assist in logging. Exposed in the trench wall were four distinct layers, all of which extended the complete length of the excavation. The oldest layer, denoted as Unit A, was exposed at the bottom of the trench wall and floor. Only the upper 15 to 75 centimeters of the lowermost layer, was observed. Unit A was a light brown and light bluish mottled clay. This unit was plastic and heavily iron stained. Many charcoal fragments were present and the layer had a moderate blocky soil development. Overlying this unit was Unit B. The contact between Units A and B was gradational. Unit B was also a clay which ranged in thickness from 20 to 100 centimeters. This unit was light bluish gray with white zones in the upper four centimeters for most of its exposure. In the eastern 12.5 meters of the trench (from Station 25.5 to Station 38) the white zone extends throughout the thickness of Unit B. The unit is plastic with a minor amount of charcoal and rootlets present. It has a moderate to well developed soil structure (blocky). Cutting across both clay units are five sand dikes feeding the overlying sandblow. These discordant features include one thin near-vertical dike, three shallow dipping thin dikes and one thick (15 cm) shallow dipping (10-15ºNW) dike striking

N25ºE. All dikes dipped to the northwest except one, which dipped to the northeast at 30º. The overlying sand (Unit C) was from 22 to 118 centimeters thick. The sand was loose, pale yellow (2.5Y 8/2), and fine to medium grained with a minor amount of silt present. Roots from the cotton crop above were present. Charcoal fragments were scattered throughout the unit. Above the shallow dipping dike (Station 8) numerous clay clasts of Unit A and several rounded pebbles (4 centimeters in diameter) were entrained in the lower portion of the sandblow unit. Clay clasts of Unit A were also observed in the near horizontal dike at Station 13. Overlying Unit C was a plow zone of highly disturbed silty sand which range in thickness from 7 to 18 centimeters.

Nancy 2, T-2

A 34-meter long trench oriented N32ºW was excavated across a second sandblow at the Nancy 2 site (Figure 10). This trench averaged 1.9 meters deep. The east wall was cleaned, girded at a 50-centimeter spacing, logged in detail, and photographed. Portions of the west wall were also cleaned and photographed to assist in logging. Exposed in the trench wall were four distinct layers, all of which extended the complete length of the excavation. Only the upper 20 to 50 centimeters of the lowermost layer, denoted as Unit A, was exposed. Unit A was a light brown and light bluish mottled clay. This unit was plastic and heavily iron stained. Many charcoal fragments were present and the layer had a moderate blocky soil development. Overlying this unit was Unit B. The contact between Units A and B was gradational. Unit B was also a clay which ranged in thickness from 30 to 75 centimeters. This unit was light bluish gray with white zones in the upper four centimeters for most of its exposure. In the southern 12 meters of the trench the white zone extends throughout the thickness of Unit B. The unit is plastic with a minor amount of charcoal and rootlets present. It has a moderate to well developed soil structure (blocky). Cutting across both clay units are three sand dikes feeding the overlying sandblow (Figure 10). These disconcordant features include two thin vertical dikes and one thick (20 cm) shallow dipping (44ºNW) dike striking N35ºE. The sandblow (Unit C) was from 65 to 130 centimeters thick. The sand was pale yellow (2.5Y 8/2), loose fine to medium grained with a minor amount of silt present. Roots from the cotton crop above were present. Charcoal fragments were scattered throughout the unit. At the northern end of the trench (Station 1.5) a tree-root cavity infilled with sand was present. Above the shallow dipping dike (Station 10) numerous clay clasts of Unit A are entrained in the sandblow. Overlying Unit C was a plow zone of highly disturbed silty sand which ranged in thickness from 7 to 15 centimeters.

Geophysical Investigation (GPR)

Geophysical techniques have already proven to be a powerful tool to study earthquake- related features such as sand blows (Wolf, *el. al.,* 1996; Tuttle *et al.,* 1999), faults (Sexton, *et al.,* 1992) and other shallow structures (Schweig, *et al.,* 1992; VanArsdale, *et al.,* 1992; Luzietti, *et al.,* 1995). GPR technology is known to work well in dry, sandy conditions. Its application is widely utilized for environmental and engineering sciences. Available to the University of Arkansas at Little Rock is a state-of-the-art GPR unit with a suite of antennas range in frequencies from 1.5 GHz to 16 MHz.

Ground Penetrating Radar surveys were conducted at three sites, Nancy 1, Nancy 2, and a site located about 2 kilometers west of Nancy 2. Because sand thickness in most of the features we have found so far is no more than 2 meters, a 400 MHz antenna was used in all of our GPR surveys. This antenna is designed to give the best resolution in the upper 5 meters in a soil layer that is similar to the soil of the studied area. Data acquisition was done along parallel profiles that were 5 meters apart. These profiles were run normal to the long axes of the features in all three sites. The data reduction procedure

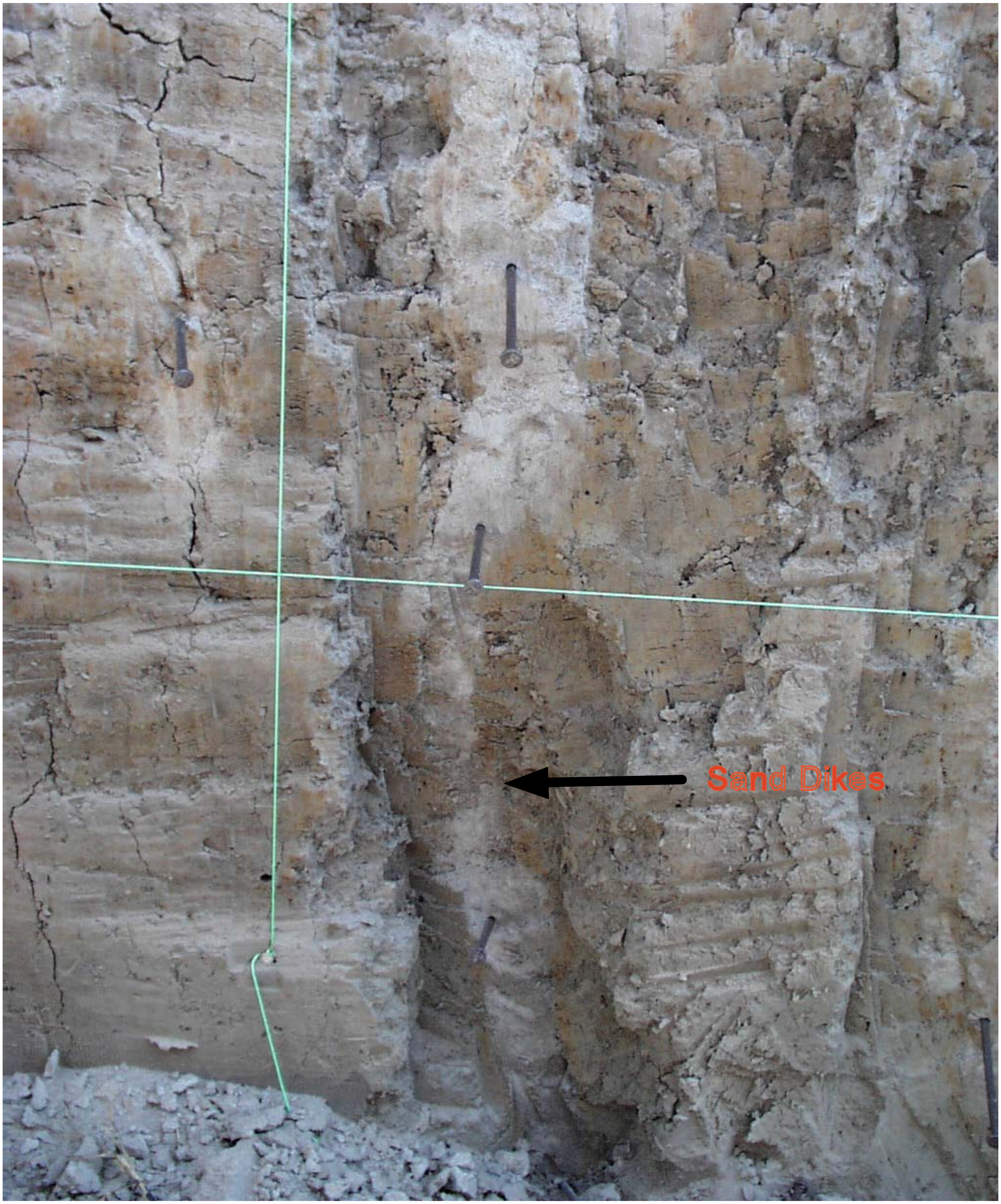
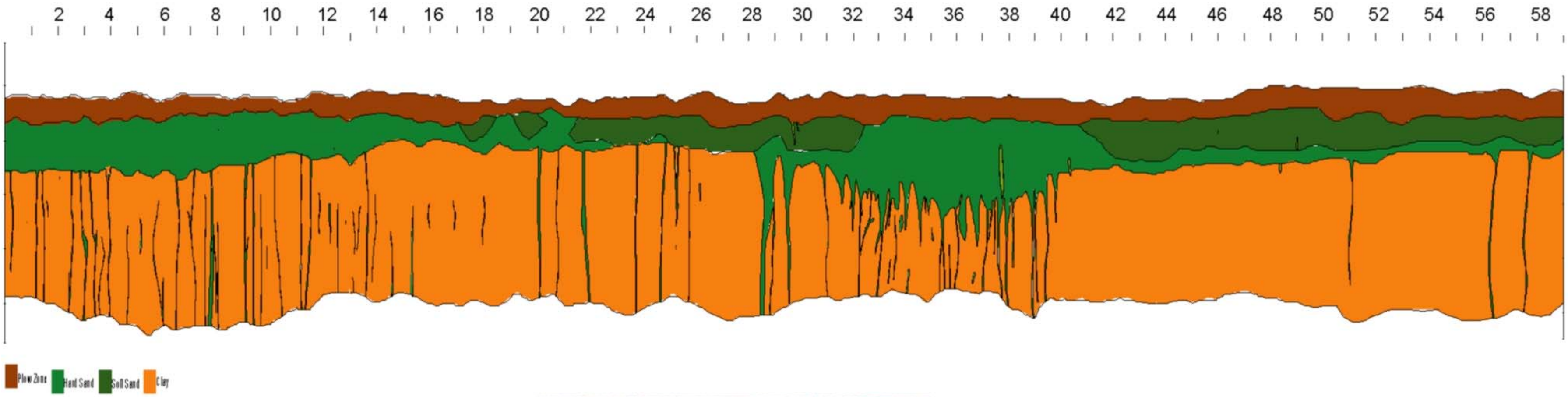
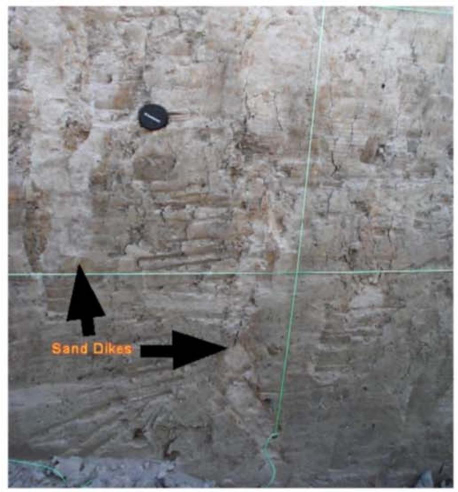
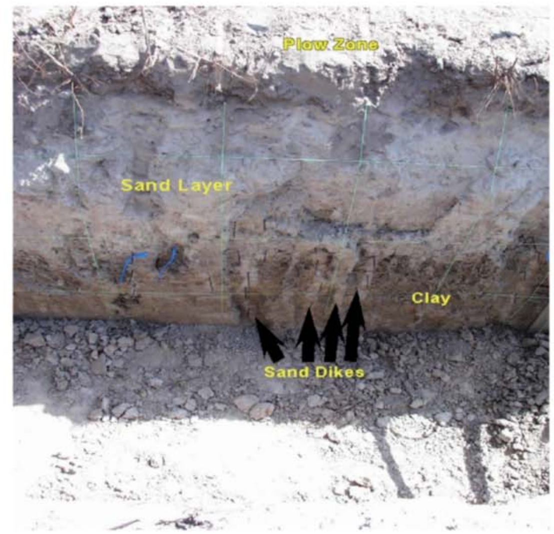


Figure 9. Sand dikes cutting through a thick clay layer. The dike shown in this figure is one of more than 45 that were logged in the 75-meter trench that was excavated across the sand blow shown in Figure 8. See the trench log in Figure 10.



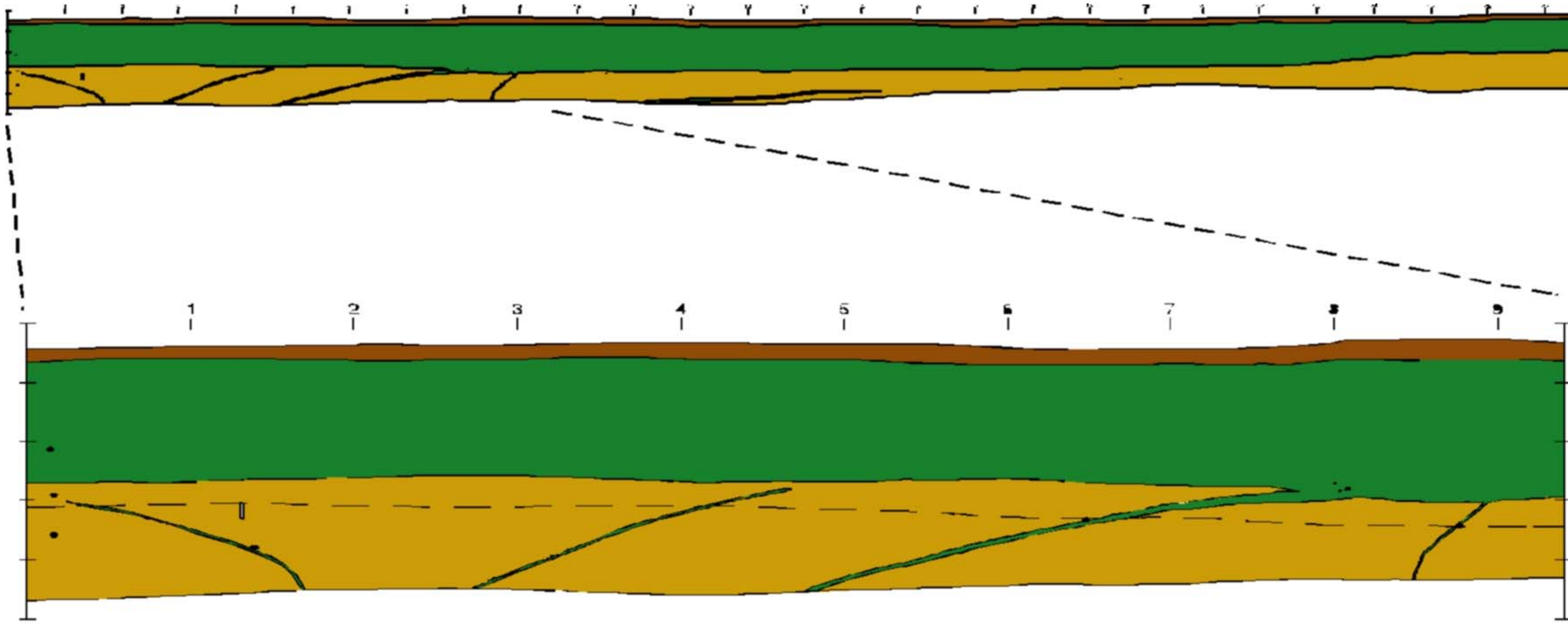
Typical trench excavated for detailed logging and sampling of suspected earthquake-related features. This trench was excavated at Nancy 1, T-1 (Figure 8).





Sand dikes cutting through a thick clay layer. The dikes shown in these plates are few of more than 45 that were logged in the 75 meter trench that was excavated across the sand blow at Nancy 1, T-1. See the trench log above.

Figure 10. Log and Photographs of the east wall of a trench excavated in the sand blow at Site 1 (Nancy 1, T-1).

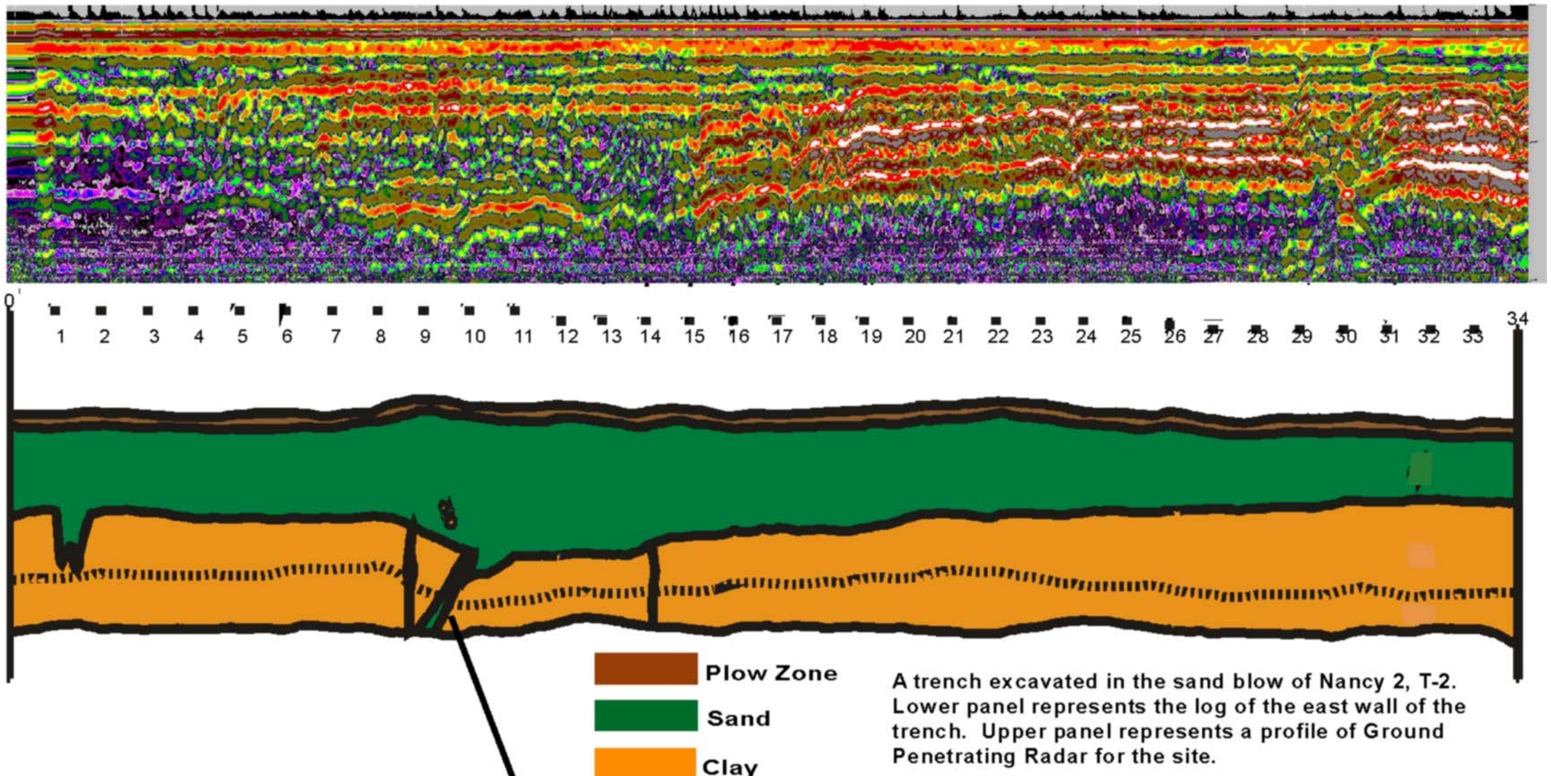


Log of Nancy 2, T-1 Trench

Low-angle sand dikes and sills (Nancy 2, T-1).

Figure 11. Log and photographs of the trench at Nancy 2 T-1 (Site 3).

Figure 12. Low-angle sand dike found in trench number 1 (T1) Nancy 2 (Site 3).



A trench excavated in the sand blow of Nancy 2, T-2. Lower panel represents the log of the east wall of the trench. Upper panel represents a profile of Ground Penetrating Radar for the site.

Clay Clasts found throughout the sand blows and sand dikes in the trench at Nancy 2, T-2.

One of the sand dikes that found to cut through the clay layer at Nancy 2, T-2.

Figure 13. Trench log and GPR profile at Nancy 2 T-2.

Figure 14. A sand dike cut through a clay layer. The dike found in Trench 2 Site 2 (Nancy 2).

included: (1) removal of the direct and the ground surface effects, (2) band-pass, high-pass, and low-pass filtration to remove noise, (3) gain control to enhance the signal of desired reflectors, (4) profile migration to remove high parabolas and improve depth determination, and (5) visualization and contouring for signal enhancement. The upper panel of Figure 10 shows a GPR profile from site Nancy 2. This profile was parallel and about 4 meters to the west of trench 2 of this site. In this profile, the contact between yellow and the purple color represent the contact between the sand and clay. Note the similarities in the morphology of this contact between GPR profile and the trench log. Note also the disruption to this contact in the area of the sand dikes.

Radioactive Carbon Dating
Initially, no funding was allocated for the project to date samples collected form the trenches. During the course of the project, the USGS regional coordinator, Dr. Eugene Schweig, provided funding for 3 samples. Data Analytic, Inc perform the dating, however, results were not conclusive to constraint the period of the liquefaction site.

Conclusions and Recommendations
Four trenches at three sites were excavated during the summer and fall of 2000. Two of these sites were near Marianna, Arkansas (Nancy 1 and Nancy 2) and one near Parkin, Arkansas (Parkin 1) (Figure 3). Each of the trenches exposed a fine to medium grained sand overlying a thick clay unit. The surficial sand deposit was found to be connected to numerous vertical- to shallow-dipping sand dikes up to 20 cm wide. The trench at Parkin 1 was excavated for the purpose of studying a 1.5 km long linear feature identified with our aerial photography and land survey. The lineament trends N56°E and the ground-surface on the southeast side of the lineament is 2.75 meters higher in elevation. No fault was discovered in the trench; however, sand and clay layers tilted to the northwest, suggesting possible subsurface faulting. Geophysical work (GPR) was conducted at three sites near Marianna. Results indicate that GPR is a very promising, cost-effective tool for sand blow studies. The large size of the liquefaction features near Marianna and their distance (≈100 km) from the active NMSZ (the 12/16/1811 event thought to be centered near Blytheville) suggest that they formed either as a result of a major New Madrid earthquake or a very large earthquake generated by a more local seismogenic source. No funding for the Radioactive carbon dating was allocated in the budget of the project. Dating result that was collected for only three samples was not conclusive. We recommend that funding should be allocated to date the rest of the samples to have more accurate results.

For future work, we recommend the excavation of 4 additional trenches at four liquefaction sites (Figures 15 – 17) that have already been identified in previous studies. We also recommend that Ground Penetrating Radar and resistivity/conductivity geophysical surveys be conducted to define the extent and size of the sand blow, to locate the main feeder dike, and help to place the trench in order to maximize the information gained while minimizing the amount of site disturbance. Analysis of the Landsat image and aerial survey need to be implemented to define the aerial extent of potential liquefaction features throughout southeastern Arkansas and to select additional sites for investigation.

Figure 15. Sand blows south of Marianna, Arkansas.

Figure 16. Small sand blows northwest of Marianna near Felton.

Figure 17. Close-up view of small sand blows northwest of Marianna near Felton.

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